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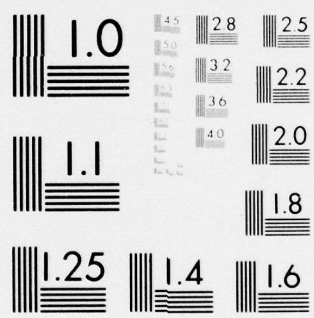
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AM-2 BASE COURSE REQUIREMENTS ON DEBRIS SUBGRADES

ENGINEERING MATERIALS DIRECTORATE

DECEMBER 1976

FINAL REPORT: MAY - AUGUST 1976

Approved for public release; distribution unlimited.

AIR FORCE CIVIL ENGINEERING CENTER

(AIR FORCE SYSTEMS COMMAND)

TYNDALL AIR FORCE BASE

FLORIDA 32403

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER 14 AFCEC-TR-76-45	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) 6 AM-2 BASE COURSE REQUIREMENTS ON DEBRIS SUBGRADES.		5. TYPE OF REPORT & PERIOD COVERED 9 Final rept. May-August 1976,
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) 10 Raymond S./Rollings		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Air Force Civil Engineering Center Air Force Systems Command Tyndall AFB FL 32403		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 63723F 21042B22
11. CONTROLLING OFFICE NAME AND ADDRESS Air Force Civil Engineering Center Air Force Systems Command Tyndall AFB FL 32403		12. REPORT DATE 11 Dec 1976
		13. NUMBER OF PAGES ~~25~~ 12 24p.
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

Available in DDC

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Civil Engineering
Landing Mats
Soil Mechanics
Bomb Damage Repair

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Existing data were used to examine the types of soils and their thicknesses that can be used as a select fill base course with AM-2 in the existing airfield bomb damage repair procedures. Dense graded, cohesionless crushed aggregate is the preferred material for the select fill base course. Sand and naturally occurring well-graded gravels are suitable alternatives. Thickness of the base course will vary from 12 to 24 inches depending on the backfill soil type and moisture content.

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PREFACE

This report was prepared by the Air Force Civil Engineering Center (AFCEC), Tyndall Air Force Base, Florida under job order 21042B22. This report summarizes work done between May and August 1976. Captain Raymond S. Rollings was the project engineer.

This report has been reviewed by the Information Office (OI) and is releasable to the National Technical Information Service (NTIS) where it will be available to the general public including foreign nations.

This technical report has been reviewed and is approved for publication.

RAYMOND S. ROLLINGS, Capt, USAF Project Engineer	GUY P. YORK, Lt Col, USAF Director, Engrg Materials
ROBERT E. BRANDON Technical Director	ROBERT M. ITEN, Col, USAF Commander

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

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SECTION I

INTRODUCTION

Current USAF Bomb Damage Repair (BDR) procedures require the use of debris backfill followed by a 1-foot base course of select fill and a surfacing of AM-2 mat to complete expedient repairs to bomb cratered runways. This select fill serves two purposes. First, it reduces the stresses developed in the debris backfill. Additionally, it protects the AM-2 landing mat panels from puncture and damage from pavement fragments and slabs in the debris backfill.

Current regulations provide no guidance on the acceptability of different materials as select fill, and the present requirement for a 1-foot thickness of select fill is based on very limited testing. The purpose of this report is to review available information from past tests and to develop tentative guidelines for acceptable select fill materials and the required select fill thickness over debris subgrades.

SECTION II

DEBRIS SUBGRADES

Following the detonation of a weapon in a pavement system, soil and pavement debris are ejected and deposited around the crater. When this material is used as backfill, a heterogeneous mixture of soil at varying densities and moisture contents results. This mixture may consist of soil at various densities and moisture contents and pavement fragments ranging from gravel size up to an entire slab. The debris backfill is placed in the crater without any compaction other than from operation of tracked dozers and from front-end loaders in the backfill process. Because of this equipment's low ground pressure, it is not very effective for conventional compaction but it does serve to shift the larger debris to more stable positions in the backfill. The result is a highly varying subgrade of uncertain load-carrying capacity.

This load carrying capacity of debris backfill will vary between different locations and even adjacent craters. Table 1 shows some results of soil tests on different debris backfills. Because of the random nature of the backfill, the presence of pavement fragments and limitations of the California Bearing Ratio (CBR) test itself, this information provides only an approximate measure of the backfill strength properties. Another measure may be seen in figure 1, where plate load tests results are plotted for four debris backfills. Modulus of subgrade reaction (k) for these four materials ranges from 73 to 244 pci. The peculiar shape of the curve from test 2 - 1 may be due to the effect of buried pieces of pavement below the plate. All of these tests were conducted on backfills at relatively low moisture contents, and debris at higher moisture contents may perform more poorly. The heterogeneous nature of debris backfill and the wide variety of possible soil types make selection of meaningful design parameters difficult and uncertain. A large amount of work has been done relating CBR with landing mat design, unsurfaced soil operations, and soil trafficability; therefore, CBR was selected as the most useful index property. A CBR of four was selected as a representative lower limit design value for most conditions, and a CBR value of one was selected for debris backfill containing plastic soils at high moisture contents.

Table 1. CBR OF VARIOUS DEBRIS BACKFILLS

	Location	Soil[a]	Depth[b]	CBR	MC	γ
1.	Ft Bragg	1962	(reference 1)			
	Test 1	SP	0	5	--	-
	Test 2	SP	0	4	-	--
	Test 3	SP	0	3	-	--
2.	Eglin AFB	1963	(reference 2)			
	Test 3	SP-SM	6	4	1.0	-
4.	Tyndall AFB	1973	(reference 3)			
	Test 1-2	CL	0	13	4.5	98.4
4.	Tyndall AFB	1974	(reference 4)			
	Test 1	SC	0	7	9.7	127
		SC	16	6	8.9	134
	Test 2	SC	0	9	5.5	125
		SC	12	7	4.5	122
	Test 3C	GW[c]	12	7	3.5	136

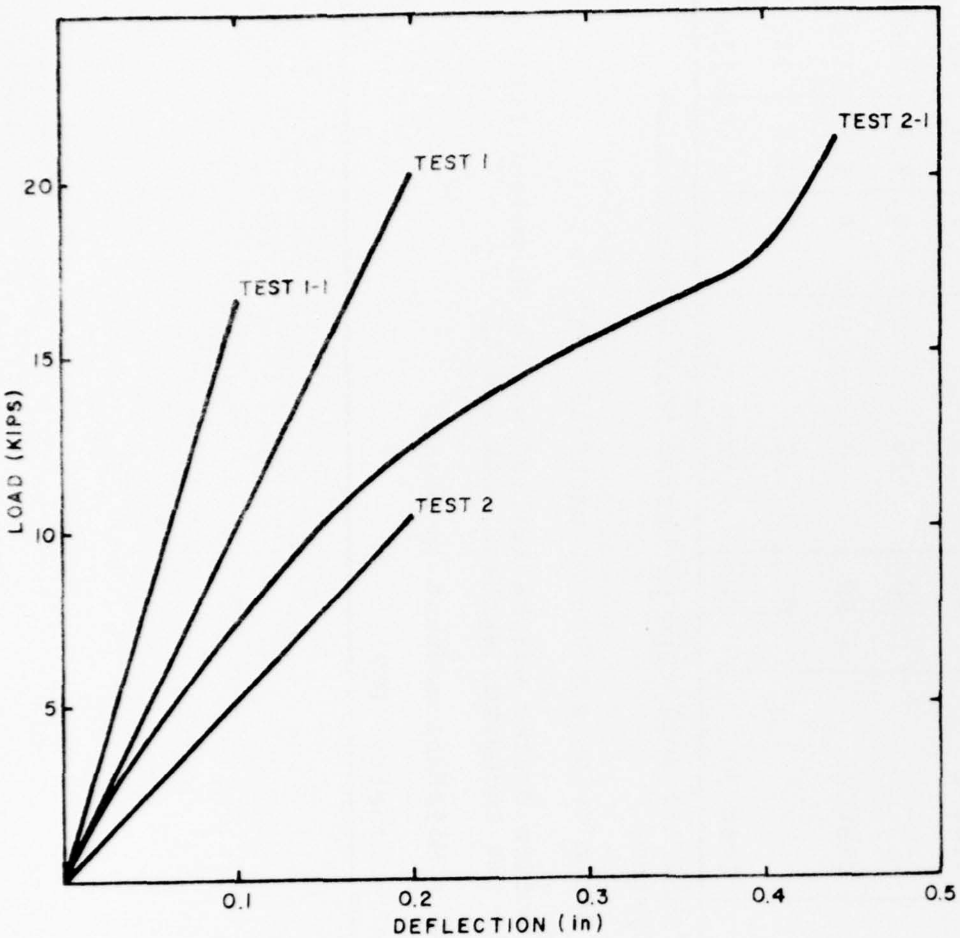
[a]Backfill soil type by United Soil Classification System.

[b]Depth below surface of backfill (in).

[c]Entire crater was backfilled with a GW select fill. At the compacted surface, CBR was 31.

MC = Moisture content (percent)

γ = Density (PCF).



Test 1-1, 1973 Tyndall Test, Reference 3
Clay (CL) Soil

Test 2-1, 1973 Tyndall Test, Reference 3
Clay (CL) Soil

Test 1, 1974 Tyndall Test, Reference 4
Sandy Clay (SC) Soil

Test 2, 1974 Tyndall Test, Reference 4
Sandy Clay (SC) Soil

Note: All tests used 30-inch-diameter plate

Figure 1. Plate Load Tests on Debris Backfills

SECTION III

MATERIAL REQUIREMENTS

The AM-2 landing mat was designed to operate on subgrades with CBR's as low as four, so material strength requirements are not unduly restrictive. The time limitations and general emergency operation conditions associated with BDR allow for only minimal compactive efforts of the base course and probably no control over the moisture of the base course. With these limitations in mind, potential materials can be divided into two categories: natural soils and crushed aggregates. Of the natural soils, all clay and silt soils, including SM and SC soils, are unsuitable because of difficulty in handling the materials and their sensitivity to moisture. Carrol and Sutton (reference 5) successfully used sand (SM-SP) as a select fill material with AM-2, but details of the test are not reported. Little information is available on the use of sand with AM-2 mat, but if very fine, silty sands are avoided, sand could be expected to perform satisfactorily as select fill for the base course.

Uniform-sized aggregates offer several potential advantages including the ability to gain density without compaction by "raining" techniques and remaining unaffected by moisture. Forrest and Shugar (reference 6) successfully obtained relative densities in excess of 80 percent for a 3/4-inch graded aggregate and a 3/8-inch uniform aggregate when rained from a height of 40 inches or more. At heights of fall below 40 inches, the uniform aggregate had higher relative densities than the graded aggregate until at a zero height of fall the uniform aggregate's relative density was 40 percent, compared to the graded aggregate's 20 percent. In contrast, a uniform sand never obtained densities in excess of 60 percent even from heights of fall of 60 inches.

When model craters were backfilled by pushing 3/8-inch uniform aggregate and 3/4-inch graded aggregate into the crater from the top, relative densities of 30 percent and 20 percent for uniform and graded aggregate were all that could be obtained. These materials were found to perform adequately in this loose state only if confined by a cap with the rigidity equivalent to 6 inches of portland cement concrete. Results of plate load tests on 3/4-inch graded aggregate at 65 percent relative density, 3/4-inch graded aggregate with moderate field compaction, and 3/8-inch uniform aggregate at

80 percent relative density are plotted in Figure 2 where it is apparent that unconfined uniform aggregate is unacceptable. Since AM-2 mat allows individual panels adjacent to the loaded panel to rotate and clear the surface (reference 3), no effective confinement of the base course exists, and use of uniform aggregates with AM-2 is not desirable.

Conventional airfield pavement construction uses crushed, dense graded aggregate in the base course to provide high stability and resistance to volume changes. In a BDR repair, however, compaction times and moisture controls required to prepare a high quality, crushed aggregate base course are not available. To be usable for BDR purposes, the aggregate must be able to obtain significant strength gain when placed with minimal compaction either wet or dry of optimum.

Table 2 presents several representative aggregate specifications and gradations from AFM 88-6 (reference 7) for a conventional airfield base course, from the Tyndall BDR field tests (references 3 and 4), from the Eglin BDR field test in 1965 (reference 5) and from base course aggregate compaction studies at the Waterways Experiment Station (WES) (reference 8). The two aggregate gradations at Eglin AFB were both tested in an uncompacted state with AM-2. Very little quantitative information was reported from this test, but Eglin No. 1, from Table 2, was recommended as the preferred gradation (reference 5). Both of the Tyndall AFB field tests used a 3/4-inch graded crushed aggregate (references 3 and 4). When some conscientious effort was made to provide minimal surface compaction, CBRs averaged 47 at 2.58 percent moisture content and 31 at 2.15 percent moisture content on tests 2 and 3C (reference 4)[1]. Even though moisture content was about 4 percent below optimum and compaction effort was limited, significant CBR values were obtained in comparison to the uncompacted aggregate (about 7 CBR, see results of test 3C in reference 4).

WES performed compaction studies of two base course gradations, WES No. 1 and No. 2, in Table 2, and concluded that cohesionless, graded, crushed aggregate base courses should be placed and compacted at the highest practicable water content. If the aggregate contained less than 10 percent material passing the 200 sieve, close moisture

[1]The BDR compactor is a Wausaw Model 60 vibratory compaction roller. Static roller weight, 4000 lb; rated impact force, 26,000 lb; width, 60 inches; roller diameter 30 inches.

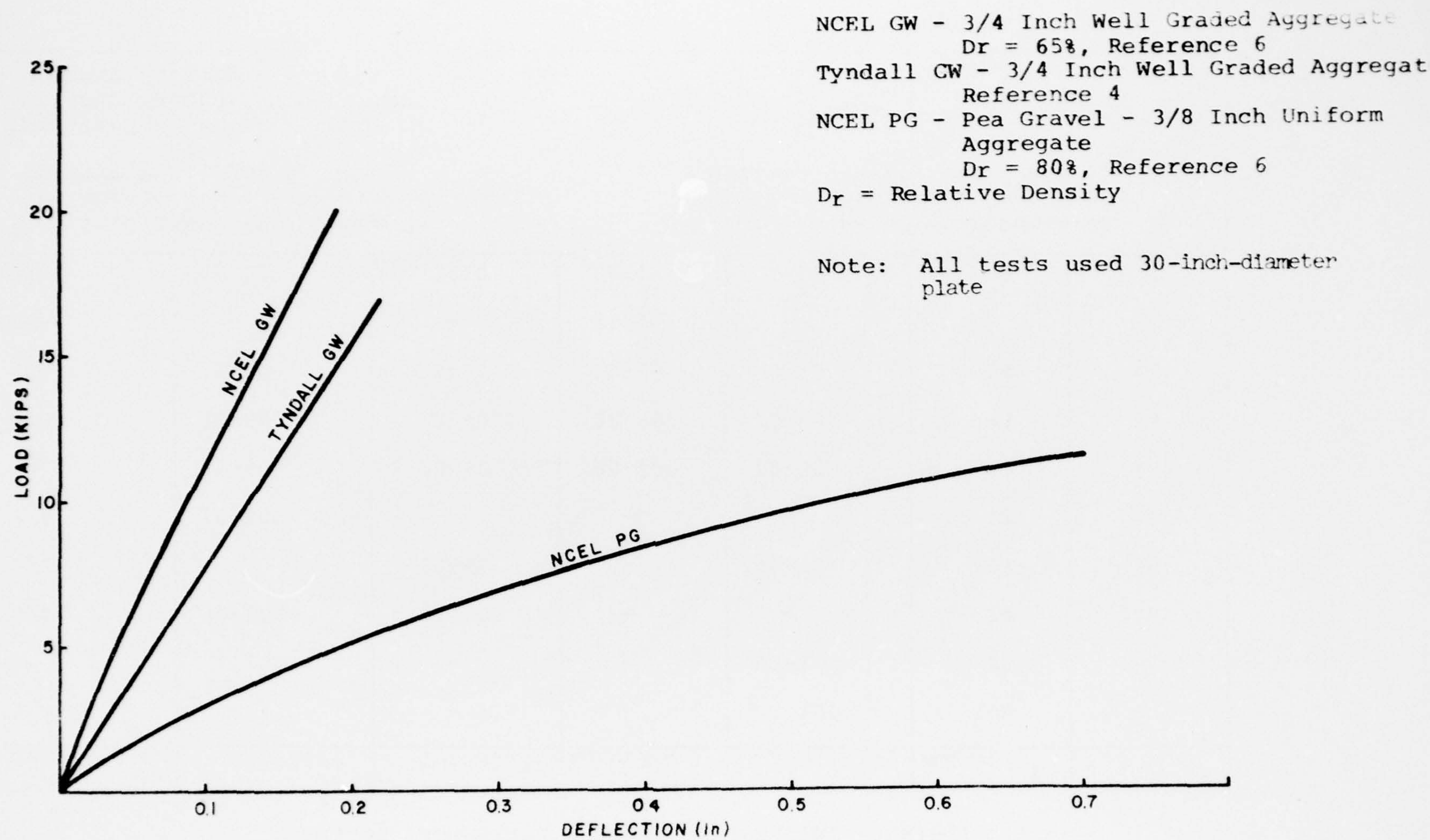


Figure 2. Plate Load Tests on Select Fill

Table 2. AGGREGATE GRADATIONS (PERCENT PASSING)

Sieve Size	AFM 86-3	Tyndall[a]	Eglin No. 1	Eglin No. 2	WES No. 1[b]	WES No. 2[c]
1 1/2	-	-	-	100	100	-
1	100	-	-	60-100	85	-
3/4	70-100	85-100	-	-	74	100
1/2	-	30-65	-	30-65	67	90
3/8	50-80	-	-	-	58	71
#4	35-65	20-40	90-100	20-50	40	40
#10	20-50	15-40	30-50	15-40	33	33
#40	5-25	5-25	18-35	5-25	14	14
#80	-	-	11-21	-	-	-
#200	5-15	0-10	0-15	5-10	9	9

[a] Modified AASHO (reference 9)
Optimum Moisture 6.4 percent
Optimum Density 154 PCF

[b] Modified AASHO (reference 8)
Optimum Moisture 6.0 percent
Optimum Density 148.8 PCF

[c] Modified AASHO (reference 8)
Optimum Moisture 6.0 percent
Optimum Density 145.7 PCF

control was not necessary, and simply adding excess water to the surface was adequate (reference 8). From the results obtained at WES and Tyndall AFB, cohesionless, graded crushed aggregate with less than 10 percent passing the 200 sieve would be an acceptable select fill which would obtain the best results when placed wet, but which can still provide acceptable strength characteristics when placed dry.

Naturally occurring gravels can be expected to have lower stabilities than the crushed aggregates, due to their rounded particle shape. This is in contrast to the high angularity and interlock of crushed aggregate particles. These natural gravels are inferior to crushed aggregate, but if they are within the base course specifications or classified as GW by the unified soil classification system, they could be used as an emergency substitute.

SECTION IV

THICKNESS REQUIREMENTS

Figure 3 shows the stress distribution for an F-4 loading calculated from a Boussinesq analysis assuming a homogeneous, elastic material and from a finite element analysis using nonlinear material properties for AM-2, a 12-inch thick crushed aggregate base course and debris backfill. Material properties for the finite element analysis are poorly defined and a complete discussion of problems encountered with finite element analysis in BDR can be found in references 6, 9, and 10. Stress levels at the debris and base course interface have been reduced to 40 and 58 psi, and 90 percent of the stress has been dissipated at 31 and 37 inches for the finite element and Boussinesq analyses, respectively. Hokanson recorded strain distribution using Bison induction strain gages as shown in figure 4 (reference 3). While the theoretical stresses lie in the upper 3 feet of the repair, Hokanson's results indicate the bulk of the strain lies between depths of 25 to 80 inches, where stress levels are low. The varying effects of moisture, density, and stress levels cannot be separated out in Hokanson's results, but the strains in the backfill are not excessive. The 12-inch select fill base course and the AM-2 are effective in reducing the surface stress by some 80 percent at the backfill and base course interface, and strains within the backfill are kept at relatively low levels.

Wolf and Ulery (reference 11) found that the required thickness of a strengthening layer beneath landing mats on low CBR soils could be conservatively approximated by the following equation:

$$t_{um} = (0.2875 \log C + 0.1875)\sqrt{\frac{P}{8.1\ CBR} - \frac{A}{\pi}} - TR$$

where t_{um} = total thickness of strengthening soil under mat, in.

C = number of coverages

P = single or equivalent single-wheel load, lb

CBR = California Bearing Ratio

A = Tire contact area, in^2

TR = Mat thickness reduction, in. (empirical, see figure 5)

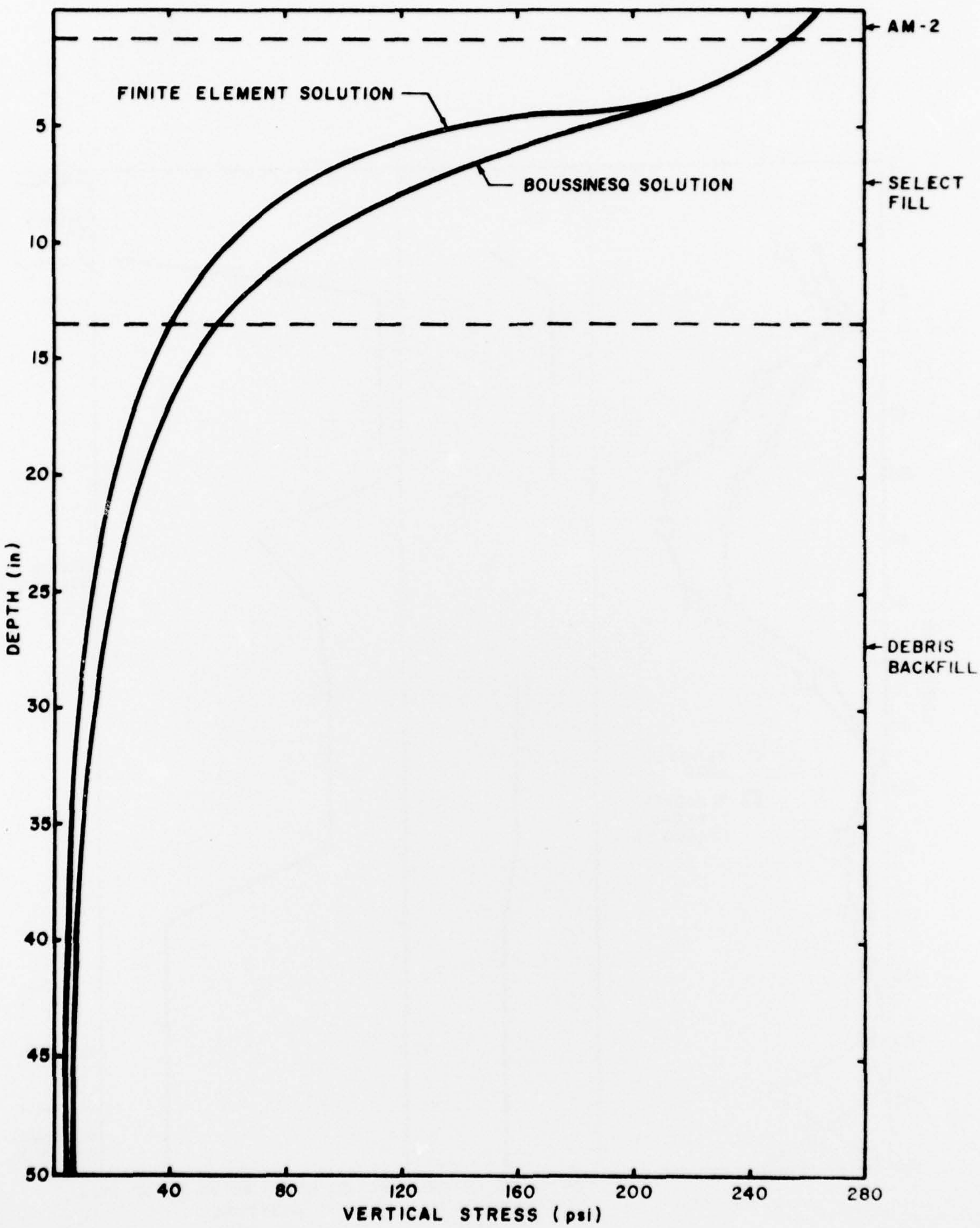


Figure 3. Calculated Stress Distribution (Reference 9)

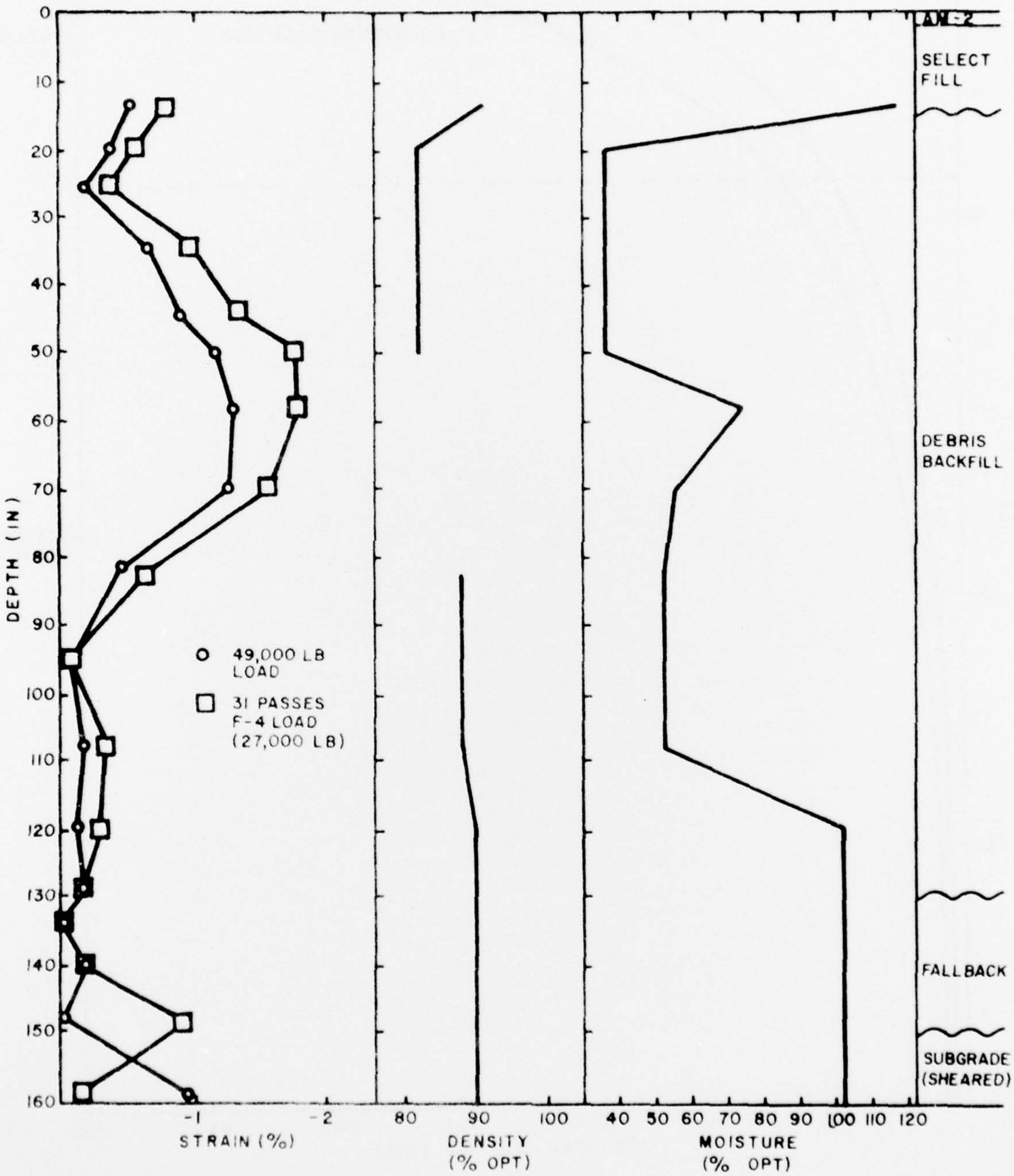


Figure 4. Measured Strains
(Reference 4)

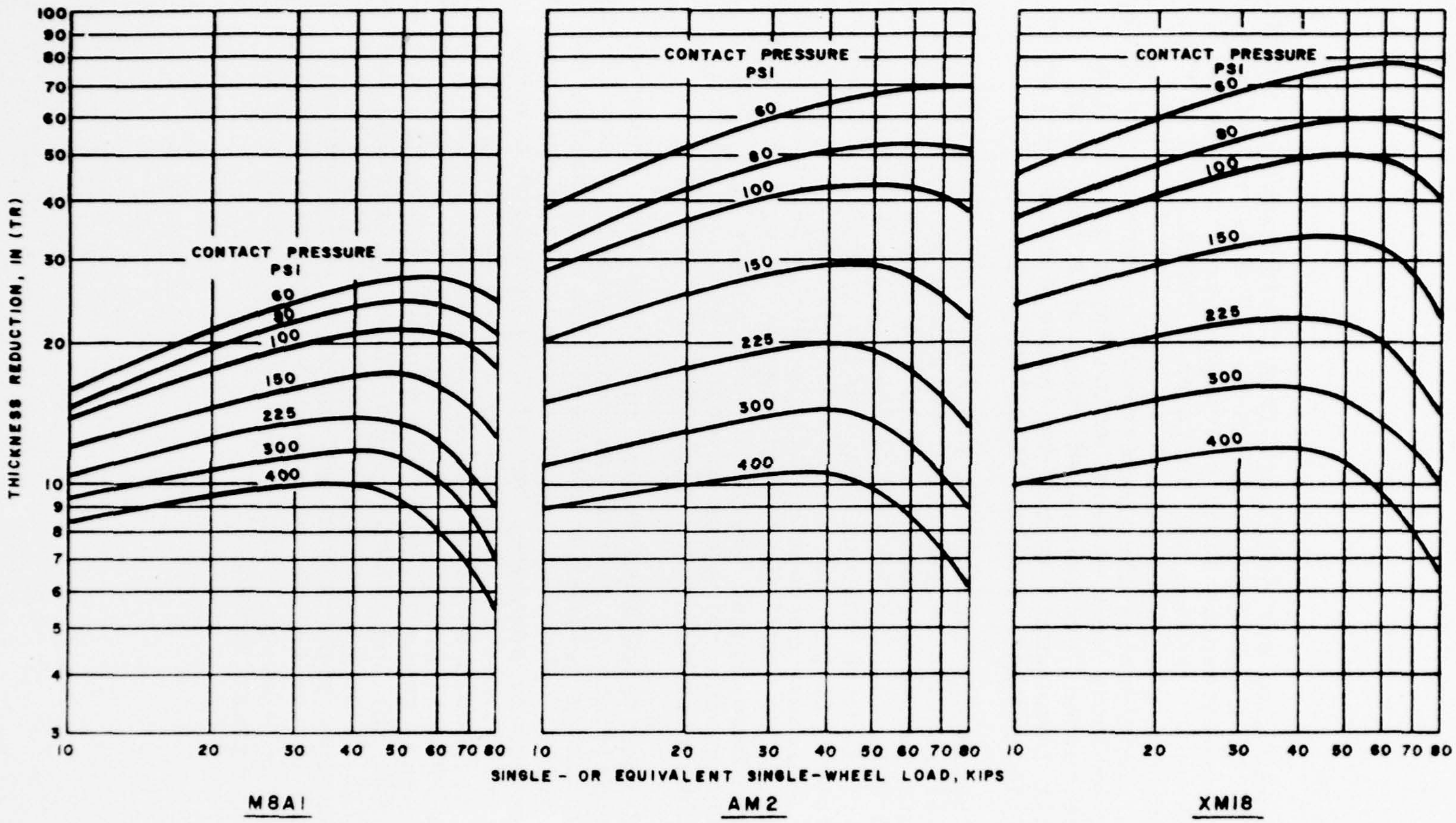


Figure 5. Thickness Reduction Curves

This equation was developed from field tests of sections with a clay (CH) subgrade with 1.3 to 3.7 CBRs and with a clay (CH) strengthening layer of varying thicknesses of 3.0 to 8.0 CBR under landing mat surfaces. Table 3 shows the strengthening layer requirements as calculated by this equation. Considering the conservative nature of the equation and the relatively weak strengthening layer used in the tests, the current procedures of using a 12-inch-thick select fill layer would appear to insure adequate capacity for a limited number of aircraft passes.

The Eglin AFB and Tyndall AFB field test results support the general results in Table 3. Thickness of select fill in these tests varied between 6 and 30 inches over subgrades of 0.0 to 13 CBR. At the Eglin AFB test, a 30-inch thickness of select fill with only a liquid asphalt surface stabilization was sufficient to prevent rutting or settling of a peat subgrade (moisture content of 242 percent, CBR of 0.0) under limited traffic. AM-2 performed adequately with an 18-inch uncompacted base course over a 1.7 CBR subgrade. At the Tyndall tests, the thickness of select fill varied from 12 to 18 inches over subgrades with CBRs of 5 to 13.

A 12-inch thick base course of select fill under AM-2 will be sufficient to insure emergency operating conditions (40 coverages as defined in AFM 86-3) for noncohesive BDR backfill soils. Where CL and ML backfill soils are encountered, this thickness is adequate, but if combined with adverse moisture conditions (saturation by rainfall or high water tables), it should be increased to 24 inches. Organic soil and CH or MH soil backfills should always use 24-inch thick base courses. These thicker base courses on plastic soils (CL, ML, CH, MH) and organic soils allow an initial layer of select fill to be placed on the low bearing backfill to insure adequate support for the dozer while it operates inside the repair to remove upheaved pavement on the crater perimeter (references 3 and 4 describe the procedure of upheaved pavement removal).

Table 3. REQUIRED STRENGTHENING LAYER THICKNESS

Aircraft - F-4, P = 27,000 lb, A = 102 in^2, tire pressure = 265 psi, TR = 18

CBR	10 Coverages[a]	40 Coverages	200 Coverages
1.0	9.3	19.0	31.0
1.5	4.2[b]	12.0	22.0
2.0	1.2	8.2	16.0
2.5	-	5.4[b]	13.0
3.0	-	3.3	9.9
3.5	-	1.7	7.8
4.0	-	-	6.0

[a]For channelized F-4 traffic, one coverage is equal to 7.36 cycles, where one cycle is a takeoff and a landing (reference 12).

[b]Minimum recommended thickness is 6 inches (reference 11).

SECTION V

CONCLUSION

The preferred material for use in the select fill base course under AM-2 mat is a dense graded, cohesionless crushed aggregate with less than 10 percent passing the #200 sieve. The fines must be nonplastic. Any of a number of standard base course specifications should prove adequate, and the AFM 86-3 or Tyndall gradations given in Table 2 are acceptable if they conform to the above two limitations on fines. Sand or naturally occurring well-graded gravel are acceptable alternative select fill material where crushed aggregate is not available. All of these materials require some compaction effort to insure proper performance.

The required thickness of the select fill base course to insure emergency operating conditions should be adjusted as follows:

Soil	Moisture	Thickness (inch)
noncohesive	Any	12
CL, ML	Low	12
	High	24
CH, MH, Organic	Any	24

Testing of types and thicknesses of select fill for use with AM-2 in expedient airfield repairs has been inadequate, and the above guidelines are only approximate. It would be desirable to conduct testing to determine the ultimate capacity of AM-2 repairs with graded aggregate and sand select fill with varying amounts of compaction. Also, other types of select fill such as naturally occurring gravels or large uniform aggregate (2 to 3 inch size) need to be tested to determine their acceptability as select fill. These materials offer some potential advantages in widespread availability or remain unaffected by adverse moisture conditions. These projects are not of the pressing priority of some other BDR projects but should be pursued as funds and time become available.

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